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Energy Procedia 56 (2014) 554 – 559

Energy Procedia

11th Eco-Energy and Materials Science and Engineering (11th EMSES)

UV photodetector based on Al-doped ZnO nanocrystalline sol-gel derived thin fims

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Abstract

Aluminum doped zinc oxide (AZO) thin films were studied as an UV photodetector devices. The AZO thin films were prepared on FTO substrates by spin coating technique. All samples exhibit prominent optical absorption edge with high optical transparency in visible range and significant blue-shift in optical band gap with increasing Al composition. The photoilluminated current increases linearly with increasing bias voltage reflecting ohmic contact behavior. The detectors have excellent ultraviolet response in wavelength region of 250-380 nm suggesting that tunable wavelength response can be obtained by increasing Al composition.

Peer-review under responsibility of COE of Sustainalble Energy System, Rajamangala University of Technology Thanyaburi (RMUTT)

Keywords: Aluminum, zinc oxide, doped, UV photodetector ;

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Peer-review under responsibility of COE of Sustainalble Energy System, Rajamangala University of Technology Thanyaburi (RMUTT)

doi:10.1016/j.egypro.2014.07.192

1. INTRODUCTION

ZnO is one of the few metal oxides which is simultaneously optically transparent and electrically conductor. Zinc oxide thin films have attracted much interest and have been used in many applications: as optically active layers in solar cells [1], transparent electrodes for flat panel displays [2], due to their important properties including high transparency low electrical resistivity good adhesion to substrate, good thermal stability, non toxicity and easy fabrication [3]. The main advantages of ZnO are n-type conductivity, low materials costs lattice parameters of (c = 5.205 Å, a = 3.249 Å), with wide direct band gap ($E_g \approx$ 3.2-3.4 eV at 300 K) and strong exciton binding energy of 60 meV [4]. The electrical conductivity in ZnO thin film is natively n-type, this originates from the Zn atoms in interstitial sites or oxygen vacancy. The increase in the ZnO conductivity can be achieved by thermal treatment with hydrogen or by appropriate doping process. An n-type conductivity of ZnO can be increased by doping with trivalent atom, such as aluminum, gallium or indium [5]. ZnO based thin films can be grown by various techniques including pulsed laser deposition (PLD) [6], RF magnetron sputtering [7], and sol-gel spin coating method [8]. For a decade, a number of researches have reported on the development of AZO-based photodetectors and many methods have dedicated to enhance its properties [9]. However, for our best knowledge, few recent works on AZO-based photodetectors prepared by spin-coating simple technique with metal-semiconductor-metal (MSM) structure have been reported. In this work, we report the study of optical properties and optical response of spin-coated AZO Photodetector deposited on FTO substrate with metal-semiconductor-metal (MSM) structure formed by silver contact.

2. EXPERIMENT

Al-doped ZnO thin films were prepared by sol-gel spin-coating method based on zinc acetate dihydrate ($(CH_3COO)_2Zn•2H_2O$)aluminum acetate ($C_4H_7AlO_5$), absolute ethanol (C_2H_5OH) and diethanolamine ($HN(CH_2OH)_2$, DEA) with concentration 0.5 M 100 ml. The solution was prepared with various Al composition x =0, 5% and 10%. The mixed solution was stirred at 100 °C for 2 h and cooled to room temperature for 24 h. All films were spin-coated on Fluorine-doped Tin Oxide (FTO) substrates and annealed at 550 °C for 5 h in air. Crystalline structure of as-grown film was characterized by X-ray diffraction (XRD) and scanning electron microscope (SEM). The photodetectors were fabricated on as-prepared films by depositing silver contacts in form of planar MSM structure. The photoresponse measurement was carried out at room temperature using Xenon arc lamp as light source dispersed by a monochromator to cover the range of 250-500 nm.

3. RESULTS AND DISCUSSIONS

Fig. 1 exhibits X-ray diffraction patterns of AZO thin films with various Al doping compositions. A broad XRD pattern appeared in all samples in the low 2θ region extending from 20° to 40° is typical diffraction pattern of a glass substrate [10]. XRD results indicated the mixture phase of wurzite-ZnO (100), (002) and (101) positioned at 2θ =31.8°, 34.5° and 36.2°, respectively. It is observed that the peak intensities of characteristic XRD peaks are weakened as the film is incorporated with Al dopant, suggesting that the crystallinity of ZnO thin films is deteriorated with increasing dopant concentration. At higher doping concentration, due to greater nuclear charge of Al^{3+}, extrinsic Al^{3+} can preferentially capture more oxygen in competition with Zn^{2+} to form amorphous phase of Al_2O_3 that can obstruct the crystal growth of the ZnO thin films [9]. The film surface morphologies revealed from SEM images in Figure 2 exhibit quite uniform crystal grains, which is in good agreement with the results calculated by XRD pattern. It is also observed from both XRD and SEM results that its grain sizes insignificantly decreases as Al composition increases.

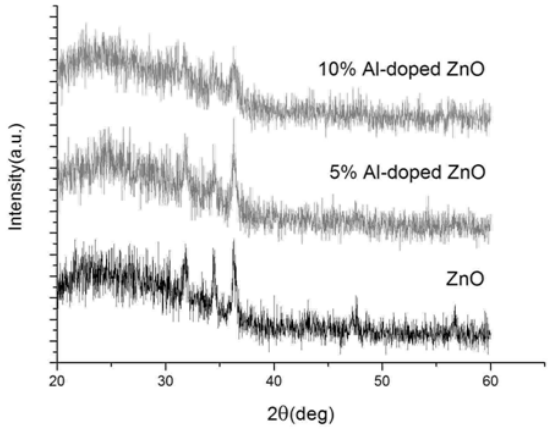

Fig. 1. X-ray diffraction patterns of Al-doped ZnO filmswith different Al doping contents.

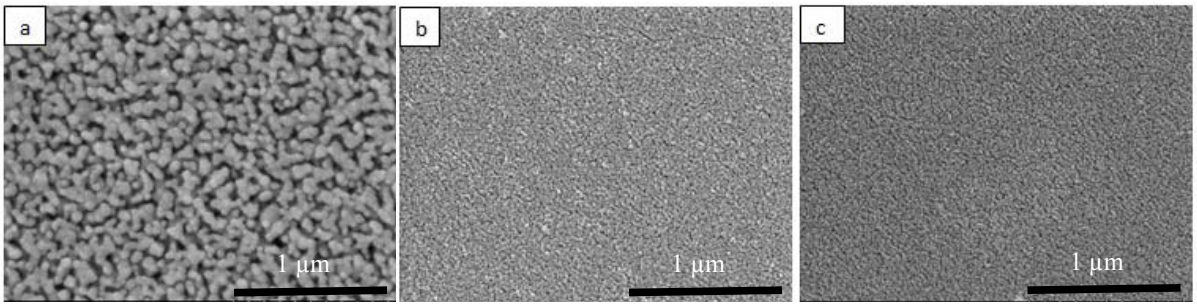

Fig. 2. SEM micrographs of (a) undoped ZnO film, (b) 5 at. % Al- doped ZnO film and (c) 10 at.% Al-doped ZnO film.

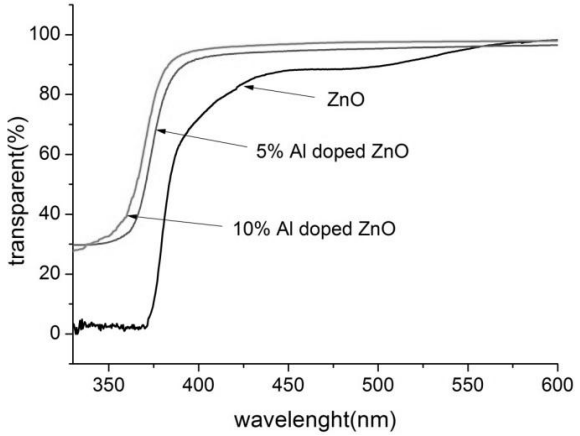

Fig. 3. Optical transmittance spectra of undoped ZnO film and Al-doped ZnO films with different Al doping contents.

The optical transmission spectra of all samples at room temperature are illustrated in Figure 3. All transmission spectra indicate sharp absorption edge and high optical transparency in visible range. Moreover, as Al composition increases, the transmission spectra exhibits the obvious blue shift of absorption edge to lower wavelength suggesting the higher shift of optical band gap of the film with increasing Al doping content. The corresponding band gap of the AZO can be varied from 3.2 to 3.3 eV by varying Al content. The band gap values of all AZO films were calculated following by the equation, (shown in Fig. 4)

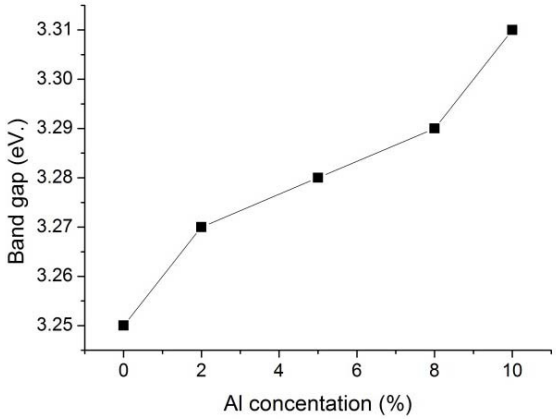

Fig. 4. The calculated optical band gap of Al-doped ZnO films with different Al doping contents.

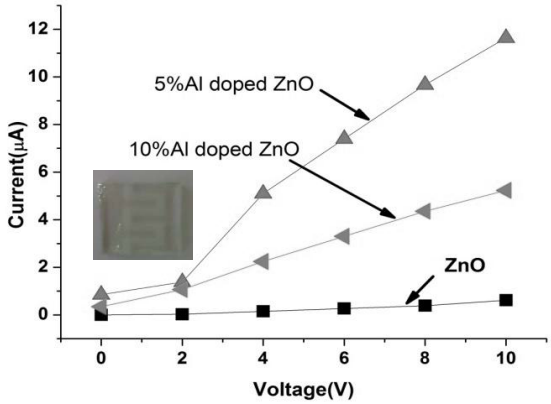

Fig.5. The photoilluminated (λ =360 nm) current of ZnO thin film and AZO films with different Al doping contents.

$$\alpha h\nu = A\left(h\nu - E_g\right)^{1/2}. \tag{1}$$

Where E_g is the optical band gap energy, A is a constant having values between 1 x 10^5 -1 x 10^6 $cm^{-1}eV^{-1}$, $h\nu$ is a photon energy, α is a absorption coefficient.

Fig. 5 demonstrates the dark and photoilluminated current of AZO-MSM photodetector (shown in the inset of AZO-MSM photodetector). At a bias voltage of 10 V, the dark and photoilluminated current of the 5 at.% AZO thin films and 10 at.% AZO of photodetector is about 0.62 nA, 11.64 μA and 5.23 μA, respectively. The low dark current in MSM detector is attributed to the good crystalline quality of the AZO thin film. The illuminated current linearly increases with increasing bias voltage indicating the good Ohmic contact of the device. Naturally, ZnO thin film is as n-type semiconductor due to its native defect of zinc interstitials and oxygen vacancies. Al doping increase carrier concentration in ZnO structure because Al has one more excess valence electron than zinc.The decrement of resistivity at doping concentration up to 5 at.% is due to the presence of one extra free electron at conduction band which come from substitutional doping of Al^{3+} at Zn^{2+} sites [9]. Comparing to dark current, photoilluminated current increases drastically by greater than three orders of magnitude suggesting the excellent S/N ratio of the device.

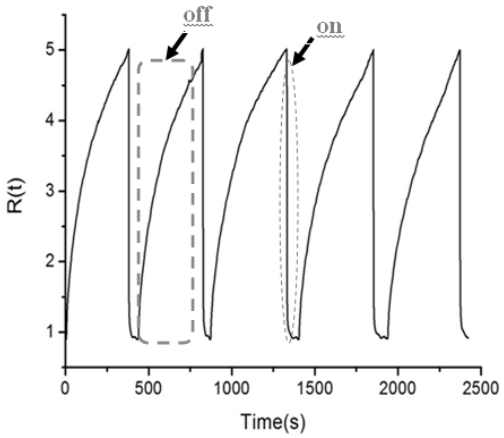

Fig.6. Time dependent photoresponse at a bias voltage of 10 V of the same sample.

Fig. 6 also shows the transient response of the measured current with switching on and off UV illumination of 5 at% AZO thin films, using Ag electrodes. The maximum photocurrent was obtained for 5 at.% Al doped ZnO thin film,Al doped ZnO thin films have excess carrier concentration due to ionization of donor in the thin film which enhanced the n-type conductivity of the thin films. Thus, the photocurrent of undoped ZnO was very low and almost invisible compared to the doped ZnO thin films. The photocurrent of doped ZnO thin films decreased at 5 at.% due to the excess Al produced defects which affected electron mobility and thus decreased photocurrent properties of the thin films [9].

4. CONCLUSION

Photoconductive UV detector using spin-coated Al-doped ZnO thin film was successfully fabricated in form of MSM planar structure. As-prepared films exhibit he deterioration of ZnO crystallinity with blueshift in optical band gap with increasing Al doping composition. The devices strongly respond to UV spectrum covering wavelength region of 250-380 nm with high S/N and prominent cutoff profile. The wavelength response of the detector can be further tuned and enhanced by Al content loading.

ACKNOWLEDGMENTS

This work has partially been supported by the National Nanotechnology Center (NANOTEC), NSTDA, Ministry of Science and Technology, Thailand, through its program of Center of Excellence Network. Authors would like to thank Rajamangala University of Technology Thanyaburi (RMUTT) for XRD and SEM measurement, King Mongkut's Institute of Technology Ladkrabang Research Fund (KMITL Research Fund) and Department of Applied Physics, Faculty of Science and Technology, Rajabhat Rajanagarindra University Chachoengsao for research fund support.

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